Response Robot Evaluation Exercise

MD-TF1 Training Academy

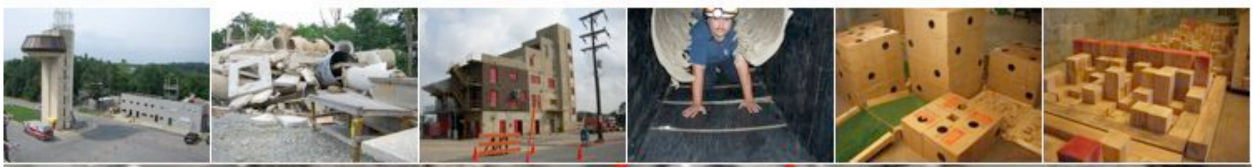
Rockville, MD

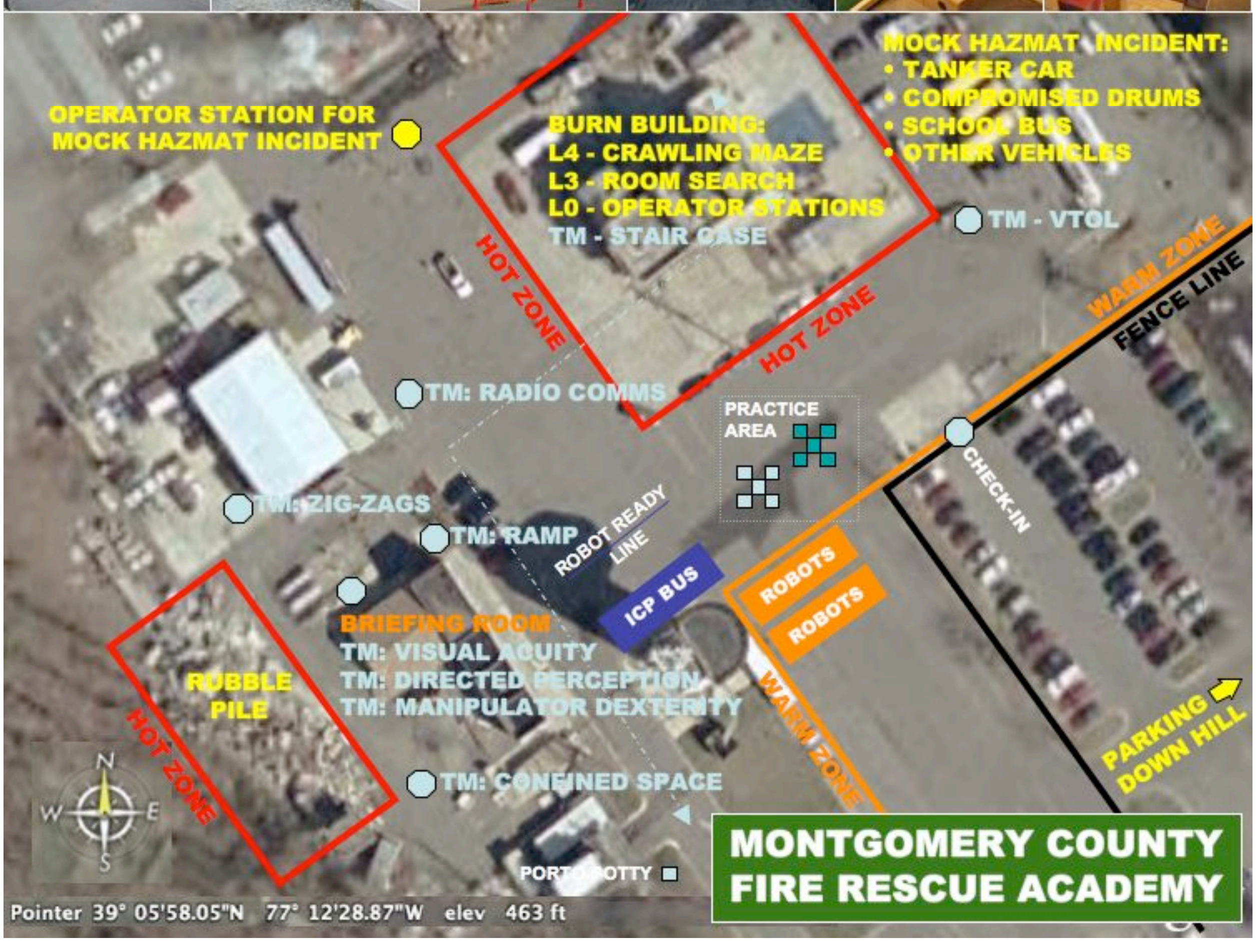
August 19-21, 2006

(with a standards meeting August 21, 2006)

www.isd.mel.nist.gov/us&r_robot_standards

usar.robots@nist.gov





Executive Summary

The Department of Homeland Security, through the Science and Technology Directorate Standards Program, is developing performance standards for robots applied to urban search and rescue (US&R). The National Institute of Standards and Technology (NIST) is leading this effort with collaboration from subject matter experts within the Federal Emergency Management Agency (FEMA) US&R Task Forces and other response organizations, along with robot manufacturers and robot researchers intent on this application domain. The resulting standard test methods are being developed within the Homeland Security Applications Committee E54 of ASTM International.

Due to the breadth and complexity of urban search and rescue missions, and the diverse and evolving technologies present within robotic systems, the definition of performance requirements and associated test methods is an ambitious undertaking. The robot providers and eventual end-users need to reach common understandings of the envisioned deployment scenarios, environmental conditions, and specific operational capabilities that are both desirable and possible for robots applied to US&R missions. Toward that end, NIST organizes events that bring emergency responders together with a broad variety of robots and the engineers that developed them to work within actual responder training facilities. These informal response robot evaluation exercises provide collaborative opportunities to experiment and practice, while refining stated requirements and performance objectives for robots intended for search and rescue tasks. The most recent event was held August 19-21, 2006 at the Montgomery County Fire Rescue Training Academy, which is the FEMA Maryland Task Force 1 Training Facility. This site contains many challenging and unique training vignettes that served well in the development and expansion of scenarios for the robots to undertake.

Responders from the FEMA Task Forces were able to experiment with a wide range of robotic platforms: 24 models of ground vehicles, 2 models of wall climbers, and 3 models of aerial vehicles. Nine different deployment scenarios were used around the Montgomery County facility. In each of these scenarios, responders used the robots to search areas of interest for simulated victims and other embedded tests. Eleven draft test methods and their associated test artifacts were evaluated and were also available to support robot/operator practice and training. These reproducible test methods, which are intended to help guide developers toward effective solutions while providing responders with known practice, training, and evaluation methods, will be refined based on the experiences and feedback from this event. The resulting these test methods, which are dubbed “Wave 1,” will be submitted to ASTM International for balloting in the coming months.

A draft version of what will eventually be a robot compendium was produced for this exercise. A listing of all the expected robots, including pictures and manufacturer’s specifications were organized by robot category and size. The draft test methods were defined, and there was a page allocated to each robot, in which the test results will eventually be filled in. Small, portable, “pocket guide” versions were distributed to all participants as a reference guide. Responders in particular, could use this to jot down notes or as a reference to find out more information about a robot.

Standards working group meetings were held to distill the lessons learned. The working groups that met were the communications, sensors, mobility, and human-system interaction. Numerous useful comments were noted, and will drive the standards development process.

Extensive data was collected throughout the event. Responders, manufacturers, and researchers were asked to provide feedback on the scenarios, test methods, and robots. Videos and images were captured of all robots in action. Measurements per the draft test methods were captured for practically all the robots (on test methods that were applicable to their particular category). In the data collection, priority given to capturing performance when the robots were operated by “experts.”

Looking toward the next wave of standards, this exercise also presented an opportunity to begin experimentation with on-board detectors for chemical and radiological sensing. Robot and radiation detector manufacturers were invited to take part in experiments that highlighted operationally-relevant US&R scenarios (e.g., radioactive sources hidden in tankers and storage drums). Robot and detector manufacturers were able to assess specific needs from "the other camp," and were able to network extensively for future collaboration and development.

This exercise was timed to coincide with two NIST-organized workshop: Performance Metrics for Intelligent Systems and IEEE Safety, Security, and Rescue Robots. Attendees from the workshops had the opportunity to travel to the Training Academy the afternoon of August 21st to view the robots being put through their paces by the responders. A significant number of media outlets also attended during this time period, resulting in local and national television and print coverage.

This report provides a summary of all the activities and results from this event. Highlight images and video of the robots can be downloaded from the NIST project home page:
http://www.isd.mel.nist.gov/US&R_Robot_Standards.

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1. Introduction and Background

The event held at the Montgomery County Fire Rescue Training Academy was part of an ongoing program funded by the Department of Homeland Security and conducted by the National Institute of Standards and Technology to develop performance standards for robots applied to urban search and rescue. During the initial phase of the program, FEMA Task Force members participated in a series of workshops in which the performance requirements for US&R robots were defined. During these workshops, potential robot deployment categories and employment roles were also enumerated. Roughly one hundred requirements were defined and organized into a systematic structure, along with thirteen robot deployment categories. The output of the program is to be a set of standard test methods complemented by usage guides to help responder entities decide which robot categories are best suited to which response scenarios. The performance test methods will provide a common language, reproducible test artifacts, and performance objectives defined by the responders to help robot developers refine their system designs and objectively measure performance. The usage guides will provide recommended performance ranges for different deployment scenarios. ASTM International is the host organization for the resulting standards, under the Operational Equipment subcommittee within the Homeland Security Applications Committee (E54.08)[1].

Due to the multi-disciplinary nature of robotics and the complexity of the urban search and rescue application, the derivation of performance test methods from the initial requirements is a multi-stage, iterative process. An initial attempt at prioritization of requirements was performed based on the responders' input regarding which requirements applied to the greatest number of robot deployment categories; in other words, the requirements deemed most essential to any robot deployment, were selected. This initial list of requirements comprise the candidate set of "Wave 1" requirements for which performance test methods are being developed and standardized in 2006-2007. Subsequent standardization waves will occur periodically as the technologies and robots mature enough to address the additional performance requirements.

Response robot evaluation exercises, such as the one held at Montgomery County's facility, introduce emerging robotic capabilities to emergency responders while educating robot developers regarding the performance requirements necessary to be effective, along with the environmental conditions and operational constraints necessary to be useful. They also provide an opportunity to refine draft or emerging test methods and associated test artifacts being developed to measure robot performance in ways that are relevant to emergency responders. Conducting these events in actual US&R training scenarios helps correlate the proposed standard test methods with envisioned deployment tasks and lays the foundation for the usage guides which will identify which robot categories appear best suited for particular response tasks. The resulting standard test methods and usage guides for US&R robots will be generated within the ASTM International Homeland Security Committee through the E54.08 Subcommittee on Operational Equipment. Furthermore, exercises allow responders as well as robot developers to gauge progress in the maturity of the various component technologies as well as the integrated robotic systems.

Two other response robot evaluation exercises were held prior to the most recent one in Maryland. The first one was held in August, 2005 at the Nevada FEMA Task Force 1 Training Facility. In April 2006, an exercise was held at Disaster City®, which is a training facility for the Texas FEMA Task Force 1, operated by the Texas A&M University's Texas Engineering Extension Service. Reports from these first two events can be found at http://www.isd.mel.nist.gov/US&R_Robot_Standards/events.

1 http://www.astm.org/

2. Participants

NIST's team of test engineers and support personnel worked with the MD-TF1 personnel on the planning and execution of this event, which accommodated roughly one hundred people and more than thirty robots across ten different scenario props at Montgomery County Fire Rescue Academy (MCFRA).

The primary participants from the emergency responder community were representatives from FEMA US&R Task Forces, as has been the case throughout the DHS/NIST performance standards program for US&R robots (see Fig. 1). Some non-FEMA responders who are members of the ASTM standards task group also participated. One canine team participated throughout the event and was joined by two more canine teams for the final day.

Figure 1: Responders Operating Robots and Exploring US&R Training Props

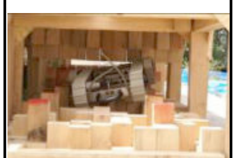
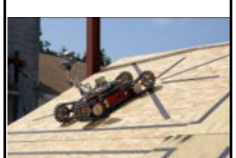
As for robot participation, there were 16 different models of ground vehicles, 2 models of wall climbers, and 3 models of aerial vehicles, including 2 helicopters. The robots represented 9 of the 13 envisioned US&R deployment categories identified in earlier workshops.[2] Table 1 lists each model of robot available on site for the responders to use. There were multiple instances of some of the more mature models available. Representatives from the robot developers/manufacturers typically deployed their own robots, but some were deployed by the Alliance for Robotic Assisted Crisis Assessment & Response (ARACAR), a non-profit group that has a large cache of robots and is collaborating on the overall robot performance standards effort.

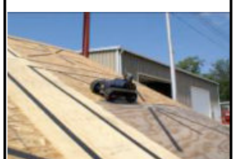
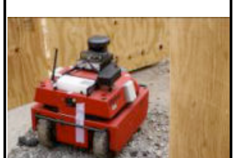
Table 1: Participating Robots

DEVELOPER (Brought by)	NAME	IMAGE (Roughly by size)	DEPLOYMENT CATEGORY
WALL CLIMBERS			
	Nanomag (magnetic)	Inuktun Services (ARACAR)	4. Ground: Wall Climber

[2] Statement of Requirements for Urban Search and Rescue Robot Performance Standards (Preliminary Version), May 2005. http://www.isd.mel.nist.gov/US&R_Robot_Standards/Requirements Report (prelim).pdf

	VRAM Mobile Robot Platform (VMRP) (suction)	Vortex HC, LLC	4. Ground: Wall Climber
GROUND			
	ToughBot	OmniTech Robotics, LLC (ARACAR)	1. Ground: Peek Robot
	Eye Ball	Remington Technologies	1. Ground: Peek Robot
	LRV	Applied Research Assoc.	2. Ground: Collapsed Structure/Stair Climber 3. Ground: Non Collapsed/Wide Area Survey
	Dragon Runner	Automatika	3. Ground: Non Collapsed/Wide Area Survey
	Variable Geometry Tracked Vehicle (VGTV)	Inuktun Services (University of Massachusetts)	1. Ground: Peek Robot 6. Ground: Confined Space Shape Shifters
	Extreme Variable Geometry Tracked Vehicle (XVGTV)	Inuktun Services (University of Massachusetts)	1. Ground: Peek Robot 6. Ground: Confined Space Shape Shifters

	IRIS	Toin University of Yoko- hama	2. Ground: Collapsed Structure/Stair Climber 3. Ground: Non Collapsed/Wide Area Survey 6. Ground: Confined Space Shape Shifters
	Bombot	West Virginia High Tech Foundation	3. Ground: Non Collapsed/Wide Area Survey
	MARCbot	Exponent, Inc. (ARACAR)	3. Ground: Non Collapsed/Wide Area Survey
	Negotiator Tactical Surveillance Robot	Robotic FX, INC. (ARACAR)	2. Ground: Collapsed Structure/Stair Climber 3. Ground: Non Collapsed/Wide Area Survey 6. Ground: Confined Space Shape Shifters
	PackBot Explorer	iRobot Corp. (ARACAR)	2. Ground: Collapsed Structure/Stair Climber 3. Ground: Non Collapsed/Wide Area Survey 6. Ground: Confined Space Shape Shifters
	PackBot EOD (w/ manipulator)	iRobot Corp. (ARACAR)	2. Ground: Collapsed Structure/Stair Climber 3. Ground: Non Collapsed/Wide Area Survey 7. Ground: Retrieval Robot
	Hibiscus	Toin University of Yoko- hama	2. Ground: Collapsed Structure/Stair Climber 3. Ground: Non Collapsed/Wide Area Survey 6. Ground: Confined Space Shape Shifters
	Cphea	Toin University of Yoko- hama	2. Ground: Collapsed Structure/Stair Climber 3. Ground: Non Collapsed/Wide Area Survey 6. Ground: Confined Space Shape Shifters

	Soryu	International Rescue Systems	2. Ground: Collapsed Structure/Stair Climber 3. Ground: Non Collapsed/Wide Area Survey 6. Ground: Confined Space Shape Shifters
	Soryu V	International Rescue Systmes	2. Ground: Collapsed Structure/Stair Climber 3. Ground: Non Collapsed/Wide Area Survey 6. Ground: Confined Space Shape Shifters
	Shinobi	University Electro Com-munications	2. Ground: Collapsed Structure/Stair Climber 3. Ground: Non Collapsed/Wide Area Survey 6. Ground: Confined Space Shape Shifters
	MARV	Mesa Robotics, Inc.	3. Ground: Non Collapsed/Wide Area Survey
	MATILDA	Mesa Robotics, Inc.	2. Ground: Collapsed Structure/Stair Climber 3. Ground: Non Collapsed/Wide Area Survey
	MATILDA (w/ manipulator)	Mesa Robotics, Inc.	2. Ground: Collapsed Structure/Stair Climber 3. Ground: Non Collapsed/Wide Area Survey 7. Ground: Retrieval Robot
	ATRV Mini	Idaho National Lab	3. Ground: Non Collapsed/Wide Area Survey
	TALON (w/ manipulator)	Foster-Miller, Inc. (NIST)	3. Ground: Non Collapsed/Wide Area Survey 7. Ground: Retrieval Robot

	ANDROS F6A (w/ manipulator)	Northrop Grumman Re-motec	3. Ground: Non Collapsed/Wide Area Survey 7. Ground: Retrieval Robot
	BOZ I	BOZ Robotics	3. Ground: Non Collapsed/Wide Area Survey 7. Ground: Retrieval Robot
AERIAL			
	AirRobot	AirRobot GmbH	8. Aerial: High Altitude Loiter
	Tethered Blimp (20ft)	ARACAR	
	Yamaha Helicopter	Syeyes Unlimited	8. Aerial: High Altitude Loiter 9. Aerial: Rooftop Payload Drop

SENSORS			
	UltraRadiac	Canberra	
	Radiogem	Canberra	
	InSpector-1000	Canberra	
	GammaRAE II Responder	RAE Systems	
	ICS-4000 Radionu-clide Identifier	XRF Corporation	

3. Scenarios

This section briefly describes the training scenarios, or props, that were used during this exercise. Responders identified access points within each scenario during the initial orientation, but had some flexibility regarding how to approach the search mission once they had a robot in hand. Some scenarios had multiple entry points.

Wall Climbing: Tower and Burn Building

Manipulator Dexterity: Urban Features

Burn Building (Level 4): Three Crawling Mazes With Obstacles And Features

Burn Building (Level 3): Rooms/Hallways With Obstacles

Burn Building (Stairwell): 5 Levels With Two Landings Between Each

Burn Building: Various External Features

Rescue Mall: Two-level Façade with Various Insertions and Props

Vehicle Accident With Chemical Spill, Radiological Hazards

Rubble Pile and Pits

4. Draft Test Methods

A set of test methods designed to address specific responder-defined robot requirements were set up throughout the site and embedded into some scenarios. This provided an opportunity to refine these test methods based on feedback from responders and developers as they used them for practice and operator training. The initial test methods and artifacts are described briefly below. Based on feedback from the participants, the resulting test methods will be introduced into the standardization process through the ASTM International E54.08.01 task group.

In this exercise, high priority was placed on ensuring that there was as close to 100% coverage by all robots of all relevant test methods. This was managed by a central dispatching station in which the Dispatch Leader (a NIST team member) had a matrix with all the robot names as columns and all the test methods as rows. Since not all test methods applied to all robots, the required tests were marked on the matrix for each robot. Robot teams were required to check in with the dispatcher, providing their robot specification sheet if they had not done so in advance. They then were assigned to a test method that was available. Figure 2 shows the central dispatching board. A "practice area" was set up near the check-in tent to allow developers as well as responders to familiarize themselves with the operation. Duplicates of some of the test methods were included in the outdoor practice area.

Given the large number of robots that had to be run through the test methods, a time limit was placed on each test for this exercise. However, this is not the intended design for the test methods. The actual test measurement methodology includes capture of the total duration of time it takes for a robot to complete a particular test's task(s). This measurement was captured for those that took less than 20 minutes.

Figure 2: The central dispatch board. The participating robots are listed in the columns and the rows represent the test methods that they are to run. Not all test methods applied to all robots.

A test method data capture sheet was designed for each test method to guide the process. The sheets for all the tests as deployed in this exercise are included below. Some modifications are being made as a result of the feedback from the participants as well as test administrators. The data capture sheets contain the generic design of the test apparatus setup. At time of performing the test, the administrator is to capture the actual configuration of the apparatus by making the appropriate marks on the forms (e.g., for a ramp test, they are to select what the angle of the ramp is). The various quantities that are to be measured in the course of the test are clearly indicated on the form. The self-declared skill level for the robot operator is captured (novice, intermediate, or expert). This is useful for benchmarking performance and for generating statistical data by experience category.

Each test method had at least one administrator. They were responsible for capturing the ground truth (i.e., particular configuration for the test setup in this particular instance). They explained the test to the robot operators and kept track of time. The operators were encouraged to capture some of the data themselves on the test method sheets (see below). The administrators helped them with this procedure. Every attempt was made to ensure safety to humans as well as to robots throughout. If a robot seemed to be in a precarious position or situation, the administrators alerted the operators. The reverse side of the form was used in this exercise to capture comments by the test administrator and by the responders and the robot team members. In particular, responders and robot team members were asked whether the test was realistic enough (i.e., whether it captured representative elements of tasks that would be performed in the field during search and rescue) and whether the test was fair.

A supporting component of the overall standards development program is the compendium of robots. This will be a comprehensive listing of all robots that have run through the tests methods (once they've been approved by the consensus standards process). The results of the test methods will be listed for each robot (where applicable) alongside images of the robot and manufacturer-provided specifications. To provide a flavor for this eventual deliverable and to help the responders capture their own observations and impressions of the different robots, a preliminary version of the compendium was produced for this exercise. In the form of a booklet that could be easily carried around, the "pocket guide" had manufacturer's specifications for each robot, as well as a page to hold the test method results. The results were not filled-in, but were meant to give the participants a feel for what will eventually be captured in the robot performance tests. Robots were grouped by Ground, Aerial, Aquatic, and Wall Climbers, and were listed within each group by increasing size. Additional sections included a site overview map, program and event introductions, information about sensors that were paired with robots, safety guidelines, and a description of each test method. Several users of the guides found the photographs useful in recognizing robots as they traversed the various test methods and scenarios. Figure 3 shows the cover of the pocket guide and a sample of the pages for a ground robot.

Figure 3: Pocket Guide

Logistics

Initial, high priority, and easily measured aspects of how robots would impact the logistics within a response organization are being included in the first wave of standard test methods. Figure 4 shows the form that captures all the measurements within the Logistics area. The different types of requirements that drove the test methods are listed below.

Logistics – Cache Packaging – Volume

This simple test method addresses the requirement that the robot and all associated components (such as the operator control unit and spare parts) must be compatible with the responders' cache packaging and transportation system. Based on responders' definitions of the metric, three standard packing cases were available for the manufacturers to determine which ones were required to contain the entire robotic system.

Logistics – Cache Packaging – Weight

This simple test method addresses the requirement on the part of the responders that they be able to move and store all equipment using existing methods and tools. A scale was available for robot manufacturers to weigh their robotic system.

Logistics – Setup Time

In this test method, the robot manufacturer or developer has to indicate the amount of time it takes (on average) for the robot to be set up at a deployment site. This covers the entire process from unpacking to the time when the robot is ready to be used in a mission.

Logistics – Tools Required

This test method addresses the requirement on the part of responders to know what types of tools are required for servicing a robot in the field.

Logistics – Downrange weight

This test method captures the weight of the robot and of the operator control unit when the robot is deployed. This measure informs responders about what weight they can anticipate having to carry into downrange from the base of operations.

NIST
National Institute of Standards and Technology
Technology Administration, U.S. Department of Commerce

Developing

Standard Test Methods For Response Robots

CACHE PACKAGING

ROBOT: ________________ ☐ TETHER ☐ RF

OPERATOR: ________________ ORG: _________________

SKILL LEVEL: ☐ NOVICE ☐INTERMEDIATE ☐EXPERT

INSTRUCTIONS: 1) NOTE THE NUMBER OF EACH PACKAGING CONTAINER NECESSARY FOR ROBOT TO DEPLOY FOR 10 DAYS, WITHOUT RE-SUPPLY FOR THE FIRST 72 HOURS. 2) TIME THE SETUP PROCESS UNTIL READY TO GO DOWN RANGE. 3) NOTE THE TOOLS NEEDED TO PERFORM SETUP AND REPAIR. 4) WEIGH THE ROBOT AND OPERATOR INTERFACE.

PLANNING FOR A 10 DAY DEPLOYMENT, WITHOUT RE-SUPPLY FOR THE FIRST 72 HOURS

NUMBER OF PACKAGES: ____ PELICANS: _________ lbs
____ HARDIGGS: _________ lbs
____ ROPACKS : _________ lbs
____ PALLETS : _________ lbs

TOTAL WEIGHT: _________ lbs

SETUP TIME: START TIME: _________
END TIME: _________
ELAPSED: _________ s

SETUP AND REPAIRS CAN BE PEROFRMED AT THE BASE OF OPERATIONS

TOOLS NEEDED: ☐ NONE:
☐ TYPICAL TOOLBOX
☐ ANY SPECIALIZED TOOLS: DESCRIBE: ______________________
DESCRIBE: ______________________
DESCRIBE: ______________________

DOWN-RANGE WEIGHT: ROBOT: _________ lbs OPERATOR INTERFACE: _________ lbs

TEST LEADER DATE NOTES ☐

Figure 4: Logistics Test Method Data Capture Form

Sensing – Vision System – Acuity (Near Field)

This test method captures the responders' expectation to use video for key tasks such as maneuvering (hence the real-time emphasis), object identification (hence the color emphasis), and detailed inspection (hence the emphasis on short-range system acuity). The responders noted the need to consider the entire system, including possible communications signal degradation and display quality, when testing this capability. They also noted that this requirement is closely tied to the need for adjustable illumination to avoid washing out the image of close objects. The responders made no distinction regarding tethered or wireless implementations to address this requirement. The near and far field tests are implemented together below. The data capture sheet is shown in Fig. 6. Note that, based on feedback from conducting the test at this exercise, the version of the form that was subsequently submitted to the standards balloting process was modified. This document captures the test methods as they were deployed in August 2006.

Sensing – Vision System – Acuity (Far Field)

This test method captures the responders' expectation to use video for key tasks such as maneuvering (hence the real-time emphasis), object identification (hence the color emphasis), and path planning (hence the emphasis on long-range system acuity). The responders noted the need to consider the entire system, including possible communications signal degradation and display quality, when testing this capability. They also noted that the limiting case for long-range system acuity is probably assessment of structural integrity of buildings. This requires identifying and measuring cracks in walls, inspecting the tops/bottoms of load bearing columns, and generally assessing the squareness of walls, ceilings, and floors. The responders made no distinction regarding tethered or wireless implementations to address this requirement. The associated reference test artifacts are shown below.

The visual acuity test method used both near and far field charts and hazard labels in view from a single viewing location for the robot (Fig. 5). The robots would either position themselves at the defined viewing location or were placed at the locations to save time. The operator was to correctly read the smallest line possible, which corresponds to certain lines on the real-life hazard and shipping labels.

Figure 5: Example of correlation between eye charts and domain-relevant label sizes

Sensing – Vision System – Acuity (Aerial)

This test method addresses the responder requirement to visually identify features of interest, in this case from aerial robots. The same principles guiding the other visual acuity tests are applied to this test. Eye charts are scaled up to be comparable in size to, and much larger than, hazardous materials identification placards found on rail cars. The charts are positioned vertically to simulate the orientation that hazmat placards have normally on tanker cars. If conducted from an aerial platform in flight, the test targets are marked with 1.2 m square black panels with white Xs to help the robot operators find and focus on specific targets of interest within the scenario. The Xs are placed on the ground in unique groupings. The aerial operators identify such groupings by reporting the number of Xs and overall pattern and then proceed to investigate the target of interest. The test method can be conducted with the vehicle stationary on the ground at an appropriate distance from the eye charts.

NIST
National Institute of Standards and Technology
Technology Administration, U.S. Department of Commerce

Developing
Standard Test Methods For Response Robots

VISUAL ACUITY

ROBOT: ________________ ☐ TETHER ☐ RF

OPERATOR: ________________ ORG: ________________

SKILL LEVEL: ☐ NOVICE ☐INTERMEDIATE ☐EXPERT

INSTRUCTIONS: 1) NOTE THE LIGHT LEVEL IN THE ENVIRONMENT. 2) SET THE ROBOT AT ANY PRE-DEFINED DISTANCE LINE AND NOTE THE DISTANCE AND SMALLEST CORRECT LINE READ. 3) REDUCE THAT RATIO TO THE HUMAN EQUIVALENT (20/10 MEANS THAT FROM 20FT YOU CAN READ THE 10 LINE - BETTER THAN AVERAGE). 4) THEN DO TIMED SEQUENCES ON THE TERRAINS DESCRIBED BELOW (CIRCLE IF CHOICE).

LIGHTED TARGET: _____lux

NO ZOOM DISTANCE

20

LINE READ

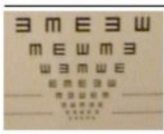
W/ ZOOM DISTANCE

20

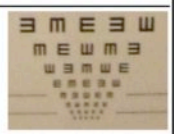
LINE READ

WHEN FINISHED READING THE FAR FIELD CHART: TIME SEQUENCE TO READ 1) LEFT SIDE NEAR FIELD, 2) RIGHT SIDE NEAR FIELD, AND THEN 3) CENTER FAR FIELD CHART AGAIN.

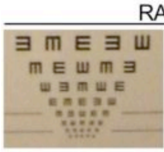
FLAT FLOOR



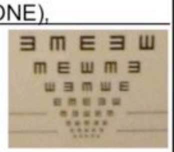
START TIME:__________
END TIME: __________
ELAPSED: __________s
______ LINES ______



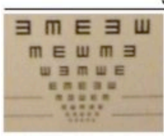
RAMP 5° 10° 15° (CIRCLE ONE)



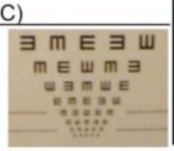
START TIME:__________
END TIME: __________
ELAPSED: __________s
______ LINES ______



STEP-FIELD (HALF-CUBIC)



START TIME:__________
END TIME: __________
ELAPSED: __________s
______ LINES ______



AVG. NEAR FIELD LINE: _____

DARK TARGET: ___lux ☐ VARIABLE ILLUMINATION
MAX. LIGHT RANGE _____m

NO ZOOM DISTANCE

20

LINE READ

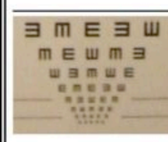
W/ ZOOM DISTANCE

20

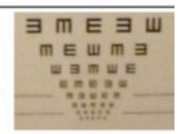
LINE READ

WHEN FINISHED READING THE FAR FIELD CHART: TIME SEQUENCE TO READ 1) LEFT SIDE NEAR FIELD, 2) RIGHT SIDE NEAR FIELD, AND THEN 3) CENTER FAR FIELD CHART AGAIN.

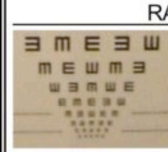
FLAT FLOOR



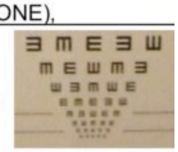
START TIME:__________
END TIME: __________
ELAPSED: __________s
______ LINES ______



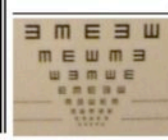
RAMP 5° 10° 15° (CIRCLE ONE)



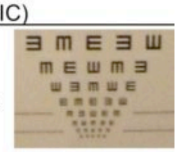
START TIME:__________
END TIME: __________
ELAPSED: __________s
______ LINES ______



STEP-FIELD (HALF-CUBIC)



START TIME:__________
END TIME: __________
ELAPSED: __________s
______ LINES ______



AVG. NEAR FIELD LINE: _____

TEST LEADER DATE NOTES ☐

Figure 6: Sensing – Visual Acuity Test Method Data Capture Form

Directed Perception (References requirement named Payload – Manipulation – Maximum Reach)

This test method addresses the responder requirement to use robotic manipulators to perform a variety of tasks in complex environments. This directed perception test captures discrete ranges of useful manipulator reach with a payload, which in this case is a camera and a light (variable illumination was very helpful in this test). The test method is meant to be flexible and extensible in terms of the payload that is being manipulated. For example, the payload could also be a sensor (e.g., to detect explosives).

The test consists of four levels of stacked boxes (46 cm tall x 46 cm deep x 61 cm wide) with 15 cm diameter access holes on all sides. Each box contains targets inside, including a near field visual acuity chart mounted to the rear of the box and a colored light stick in a known orientation centered and affixed to the bottom of the box. The access holes are vertically centered on each box, and located either on the right or left quarter line, requiring a skewed view to identify both targets inside. Robot operators identify and report the smallest readable line of the visual acuity chart along with the color and orientation of the glowing light stick. Other uses of these box stacks include canine units training with explosive ordinance sample targets inside the boxes; dogs can typically clear the lower three levels of all boxes encountered. Large robots can reach the top-level access holes but often exhibit balance issues, which are exacerbated by so-called orange (half-cubic) random step fields. Note that box stacks can be arranged so that there are multiple "cubbies" (areas semi-enclosed by 3 stacks of boxes). There will be a different data collection form for each cubby perspective. There is always one side of the stack approachable from flat flooring. The associated reference test artifacts are shown below in Figure 7, which contains the data capture form.

This data capture form contains extensive customization choices for setting up the test configuration. There are three stacks of boxes: Left, Center, and Right. There is designed flooring in the space enclosed by the left, center, and right boxes and extending linearly beyond the enclosed space.

There are 5 main categories of design choices that are to be marked on the forms prior to starting the test method execution:

- The type of flooring. The choices are oriented planar flooring or varieties of step fields.
  - Planar flooring may be flat, have a side roll with either the left or right side higher (known as "roll" configuration) or have a "pitch." A pitched floor would have an elevated center that causes a rise and a fall in the direction of approach to the center stack of boxes.
  - Step fields are constructed of sets of blocks that have different heights and follow certain trends. A "diagonal" step field would have the highest blocks along the diagonal. A "hill" design step field would have the highest blocks form a ridge in the direction of approach to the center stack of boxes. Step fields can also be constructed of to have different maximum step heights. The choices are indicated on the form as "half cubic" or "full cubic."
- The design of the box stacks. The number of boxes stacked for Left, Center, and Right is variable.
- The design of the hole pattern. For each box stack (Left, Center, or Right), there will be one hole at each level facing the interior of the "cubby." There are different possible hole positions at the top of the stack.
- The types of targets that are hidden in the boxes. Choices are near-field visual acuity charts, colored light sticks, and potentially other sensor targets, such as thermal signatures (representing "victims"), trace elements of chemicals or explosives (or simulants), or trace elements of radioactive sources.
- Optionally, the test method can capture at which distance from the center of boxes a particular signature was detected. This is used, for instance, if there is a radiological or chemical target within the stacks, it may be of interest to note from how far away the sensor onboard the robot began picking up a signal. The lower left hand corner of the form shows how to mark fixed distances from the center of the box stack in order to facilitate measuring point of initial detection.

In terms of capturing performance data during execution of the test, there are several aspects that must be noted. The overall time necessary to clear all the holes accessible by the robot is captured. For each level of each stack, the following data are obtained:

- The smallest line of the acuity chart ("E") that was read
- The orientation of the glow stick ("+")
- The color of the glow stick: Red ("R"), Green ("G"), or Yellow ("Y")
- The type of other targets found: Victim ("VI"), Chemical ("CH"), Explosive ("E"), or Radiological ("R")

The results are tabulated according to each box stack ("L," "C," and "R"). Total number of holes cleared versus total number emplaced, number of eye charts seen versus number emplaced, the average smallest line of the eye chart that could be read, number of correct glow stick orientations and colors, and the number of other types of targets seen versus number emplaced. The distance at which a sensor signature such as chemical, explosive, or radiological was first detected is also captured. This is indicated by noting in which of the surrounding rectangles the robot was when the detection first occurred.

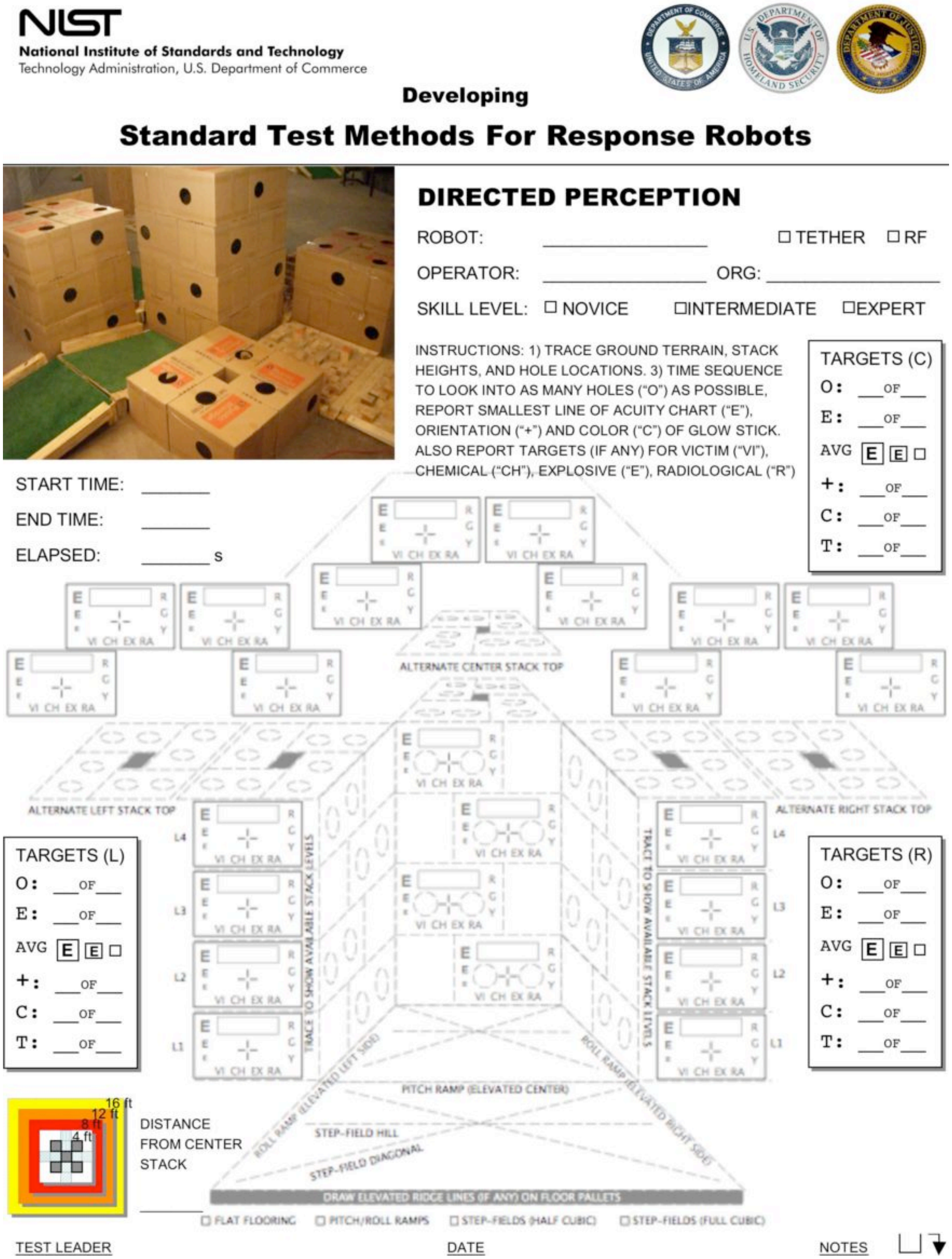


Figure 7: Sensing – Directed Perception Test Method Data Capture Form

Manipulator Dexterity (References Requirement Labeled Payload – Manipulation – Retrieval)

This test method addresses the responder requirement to retrieve objects, not necessarily configured for robot manipulators, within complex environments. This manipulator dexterity test setup is similar to the directed perception test in that it involves a stack of four shelves at 46 cm incremental elevations (the third shelf is roughly at table height) and surrounded on three sides by so-called orange (half-cubic) step fields, with one side of the shelving stack accessible from flat flooring. Each shelf contains items that must be picked up by the robot. On each shelf, items are centered on a 3x3 grid, with consistent orientations to challenge particular gripping approaches. The majority of the items to be picked up are wooden blocks, which are 4x4 posts cut into three cubic lengths, so are larger than most grippers can grab in at least one dimension. Other items may be available to be grasped (especially if the test is aimed at bomb-disposal robots rather than US&R robots). These include mineral water bottles and simulated pipe bombs. Robot operators approach the shelf stack from a flat flooring side and remove as many blocks as possible from as many shelf levels as possible. They repeat the task from a step field side to complicate robot orientations and mobility. The number and locations (x, y, z) of all blocks removed from any given side are noted. The associated reference test artifacts are shown below as part of the data capture form in Figure 8.

This data capture form contains extensive customization choices for setting up the test configuration. There are three stacks of shelves: Left, Center, and Right. There is designed flooring in the space enclosed by the left, center, and right shelves and extending linearly beyond the enclosed space.

There are 5 main categories of design choices that are to be marked on the forms prior to starting the test method execution:

- The type of flooring. The choices are oriented planar flooring or varieties of step fields.
    - Planar flooring may be flat, have a side roll with either the left or right side higher (known as "roll" configuration) or have a "pitch." A pitched floor would have an elevated center that causes a rise and a fall in the direction of approach to the center stack of boxes.
    - Step fields are constructed of sets of blocks that have different heights and follow certain trends. A "diagonal" step field would have the highest blocks along the diagonal. A "hill" design step field would have the highest blocks form a ridge in the direction of approach to the center stack of boxes. Step fields can also be constructed of to have different maximum step heights. The choices are indicated on the form as "half cubic" or "full cubic."
- The design of the shelving units. The number of shelves stacked for Left, Center, and Right is variable.
- The types of targets that are placed on the shelves in a 3 by 3 grid. Choices are typically wooden blocks, but may occasionally be another item, such as a mineral water bottle.
- The orientation of the blocks within each shelf. Typically they will follow the same pattern.

In terms of capturing performance data during execution of the test, there are several aspects that must be noted. The overall time necessary to clear all the holes accessible by the robot is captured. For each level of each stack, the following data are obtained:

- Each block that is removed from each level is marked on the figure. A distinction is made between the perimeter angled blocks ("B") and the center blocks ("O"). Total number of blocks removed at each level is computed.
- The total time it took for the robot to remove all of the blocks it was able to. The blocks may be dropped on the floor once they have been picked up by the robot.

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MANIPULATOR DEXTERITY

ROBOT: ________________ ☐ TETHER ☐ RF

OPERATOR: ________________ ORG: ________________

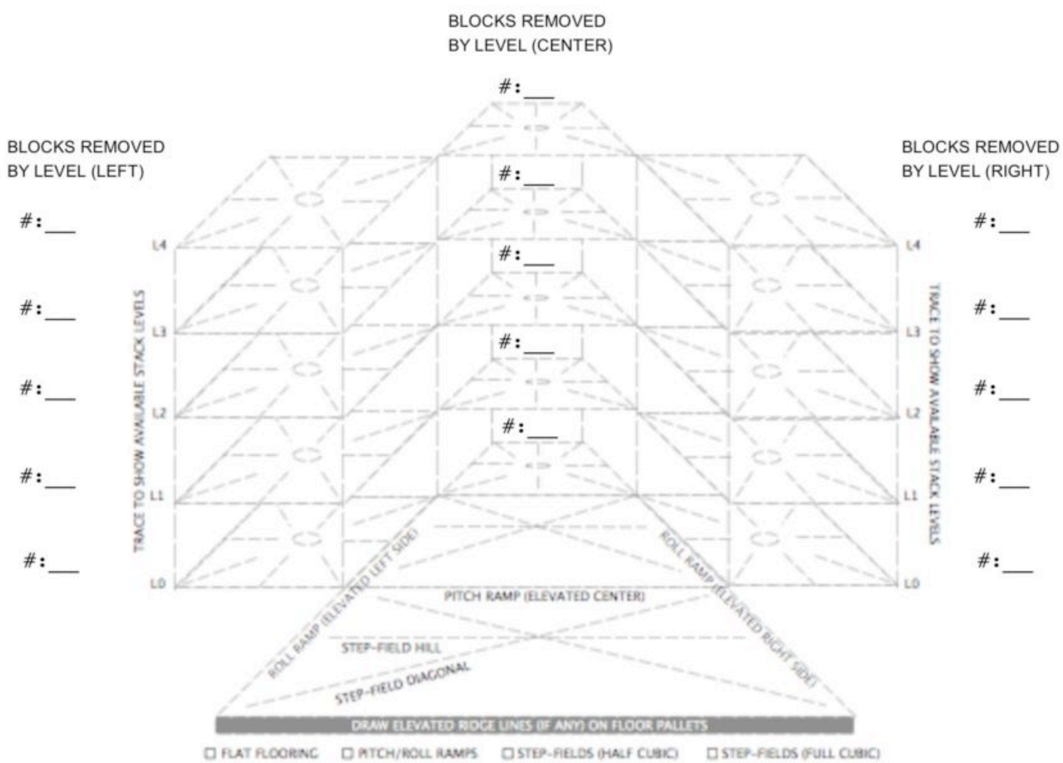
SKILL LEVEL: ☐ NOVICE ☐INTERMEDIATE ☐EXPERT

INSTRUCTIONS: 1) TRACE GROUND TERRAIN AND STACK HEIGHTS. 2) TIME SEQUENCE TO REMOVE AS MANY BLOCKS FROM EACH LEVEL AS POSSIBLE (DROPPING BLOCKS ONTO FLOOR IS OKAY). 3) TRACE WHICH ANGLED BLOCKS ("B") AND CENTERED OBJECTS ("O") ARE REMOVED. 4) NOTE ELAPSED TIME.

START TIME: _______

END TIME: _______

ELAPSED: _______ s



TEST LEADER DATE NOTES ☐

Figure 8: Manipulator Dexterity Test Method Data Capture Form

Human/System Interaction – Acceptable Usability

This test method addresses the responder requirement to operate robotic systems simply and effectively. The metric measures the percent of timed tasks operators can successfully complete. The operators are to navigate a maze-like course from start to finish. This test also measures the situational awareness of the operator as s/he navigates through an unknown environment using only the onboard sensors of the robot or any assistive technologies such as map-building or sensor fusion that may be available. Figure 9 shows the data capture form and a diagram of the maze that was built for the exercise. The total amount of time required to traverse the maze was captured and the test leader noted problem areas (for example dead-ends) if any.

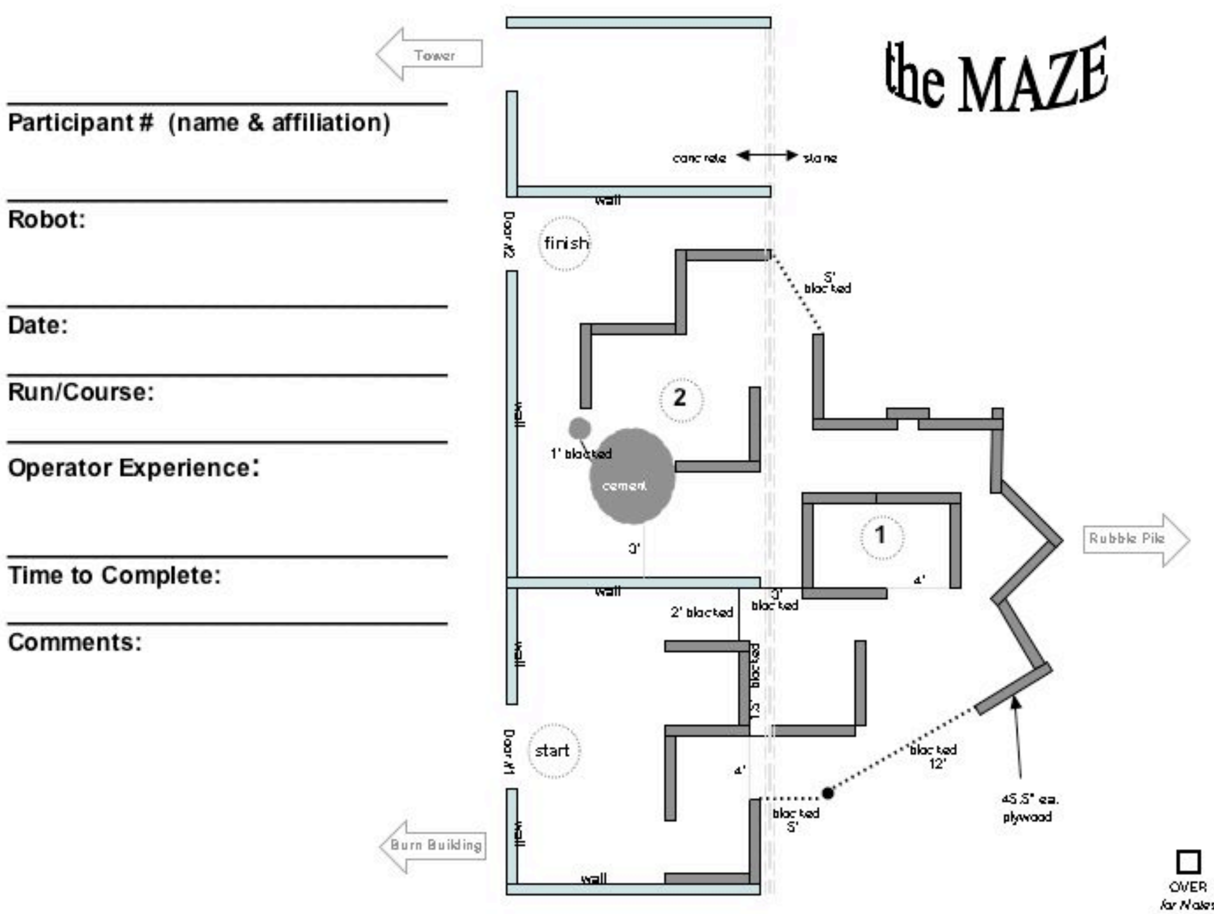


Figure 9: Human-System Interaction - Acceptable Usability Test Method Data Capture Form

Communications – Range – Line of Sight (LOS)

Communications – Range – Beyond Line of Sight (BLOS)

This test method addressed the responder requirement to project remote situational awareness at some standoff distance (with line of sight) as well as around corners of buildings and into compromised or collapsed structures. A single form covered capture of performance data for both line of sight and beyond line of sight tests. The robot's communications frequencies for transmission (Tx) and reception (Rx) were noted. There could be two different channels – one for command information and one for data.

Line of Sight. During this test, the operator navigated a robot down a linear path with direct line of sight to the control station. Along the way, there were some visual targets (eye charts) placed for the operator to view through the robot's camera(s) as a way of capturing the quality of the video transmission at the given distance. For this test, the distance from the start point to each target was noted, as was the smallest line of the eye chart that could be read by the operator. Time to navigate to each target location was noted.

Beyond Line of Sight. In this test, the operator navigated the robot down a linear path towards a tall building. The operator was to try and circumnavigate the building. There were visual targets (eye charts) placed at regular intervals on the sides of the building, intended to capture the quality of the video transmission at each location. The robot path was to be within 1 m of the side of the building. The distance to the first turn around a corner (which was the transition from having line of sight to non-line of sight, was captured on the form. Also noted were the distances to each of the visual targets and the smallest line that could be read by the operator. Times required to reach the first corner of the building and each of the targets was captured.

Figure 10 shows the data collection form for the communications tests. Section 5 contains more information about the tests conducted on the robot wireless communications systems.

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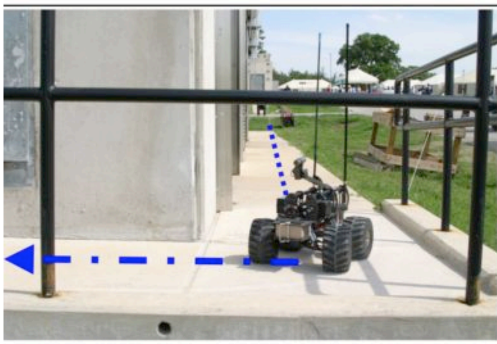

RADIO COMMUNICATIONS

ROBOT: ____________ ☐ TETHER ☐ RF

OPERATOR: ____________ ORG: ____________

SKILL LEVEL: ☐ NOVICE ☐INTERMEDIATE ☐EXPERT

INSTRUCTIONS: 1) MEASURE DISTANCE THE ROBOT TRAVELS WITHIN LINE OF SITE AND BEYOND LINE OF SIGHT, WHILE READING VISUAL ACUITY CHARTS AT PERIODIC INTERVALS. 2) MEASURE ELAPSED TIME FROM ARRIVAL AT PRE-DEFINED TARGET READING LOCATIONS -- CLOSE RANGE TO TARGET FOR CONSISTENT COMMS SITUATION ACROSS TRIALS. 3) NOTE THE SMALLEST CORRECT LINE AND ELAPSED TIME.

RADIO FREQS:

TX1: ________ MHz TX2: ________ MHz

RX1: ________ MHz RX2: ________ MHz

BUILDING

NON LINE OF SITE PATH

LINE OF SITE PATH

DIST. TO 90* TURN : ______ m

TURN TIME: ________

1ST TARGET: ________ m
SMALLEST LINE:________
LINE NUMBER: ________
ELAPSED TIME: ________ s

2ND TARGET: ________ m
SMALLEST LINE:________
LINE NUMBER: ________
ELAPSED TIME: ________ s

3RD TARGET: ________ m
SMALLEST LINE:________
LINE NUMBER: ________
ELAPSED TIME: ________ s

AFTER 90° TURN:

1ST TARGET: ________ m
SMALLEST LINE:________
LINE NUMBER: ________
ELAPSED TIME: ________ s

2ND TARGET: ________ m
SMALLEST LINE:________
LINE NUMBER: ________
ELAPSED TIME: ________ s

3RD TARGET: ________ m
SMALLEST LINE:________
LINE NUMBER: ________
ELAPSED TIME: ________ s

4TH TARGET: ________ m
SMALLEST LINE:________
LINE NUMBER: ________
ELAPSED TIME: ________ s

5TH TARGET: ________ m
SMALLEST LINE:________
LINE NUMBER: ________
ELAPSED TIME: ________ s

TEST LEADER DATE NOTES ☐

Figure 10: Communications - Wireless LOS and BLOS Test Method Data Capture Form

Zig-zag Dashes (References Requirement Labeled Mobility – Locomotion – Sustained Speed)

This test method measures robot speeds and basic maneuverability on different surfaces while maintaining a proscribed course. The courses required predictable changes in direction (zig-zags) over different ground surfaces, for example grass (long or short), gravel, pavement, or NIST's random stepfields. The stepfields are designed to be an abstracted, but repeatable, rubble-like terrain. The form associated with this test method is shown in Figure 11.

There were three dashes set up for the exercise: unpaved, paved, and red stepfields. The red stepfields provide more challenging terrain to negotiate than the orange ones which were used in other test methods primarily to present changes in orientation to the robot platform, rather than actual mobility tests. In terms of customization of the forms, the test leader had to mark the dominant features of the step fields (by darkening the appropriate lines: diagonals, mid-field hills, etc.). For each run (a single zig zag) attempted, the test leader timed the robot as it went through the course in one direction and then back towards the start point. If the robot was unable to complete the course, the test leader noted the furthest location it attained. Any bumping of the side walls was noted as well.

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ZIG-ZAG DASHES

ROBOT: ________________ ☐ TETHER ☐ RF

OPERATOR: ________________ ORG: ________________

SKILL LEVEL: ☐ NOVICE ☐INTERMEDIATE ☐EXPERT

INSTRUCTIONS: 1) USE GRAPHIC FOR APPROPRIATE TERRAIN TYPE -- IF STEPFIELDS, TRACE ELEVATED TERRAIN RIDGES. 2) TIME SEQUENCE FOR ROBOT TO TRAVERSE THE ZIG-ZAG TO FAR END AND BACK TO START POINT. 3) NOTE LOCATIONS OF WALL BUMPING WITH A CLEAR "X." 4) NOTE THE ELAPSED TIME AND TOTAL PALLET EQUIVALENTS TRAVERSED (TRACE DOTTED PATH IF INCOMPLETE).

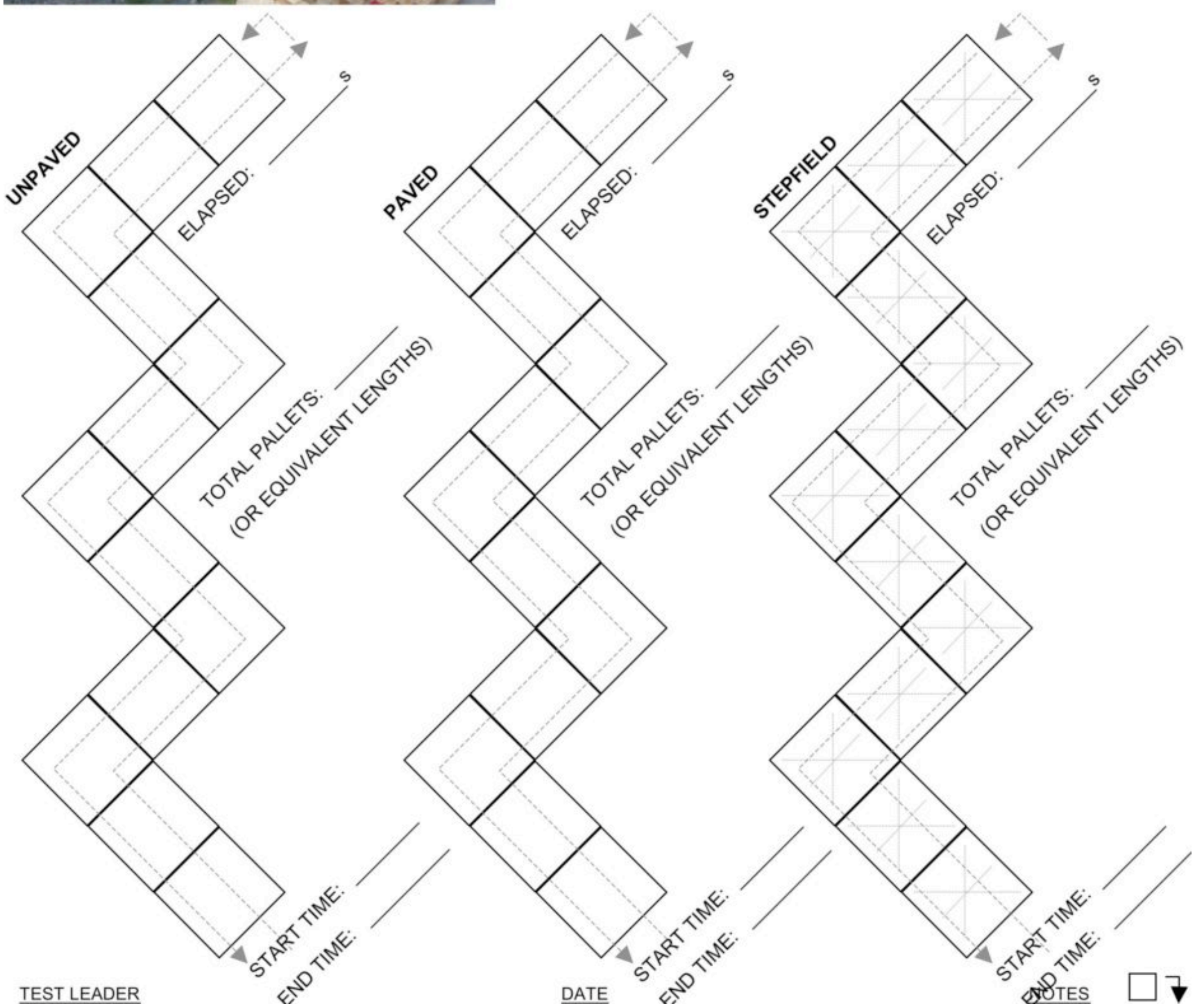

Figure 11: Mobility – Zig-Zag Dashes Test Method Data Capture Form

Mobility – Stair Climbing

This test method addresses responder requirements for mobility climbing and descending stairs. The test uses artifacts that are readily available in the training facility's scenarios. In particular, the staircase in the burn building was utilized. The specific stair artifacts will not be formally submitted to the standards process, however, fabricated versions of stairs or a description of the desirable characteristics for stairs used in the test procedures will be included in the proposed test methods. There are a multiplicity of combinations of materials and stair configurations so an exhaustive set of "reference test stairs" is not achievable.

Figure 12 shows the form used for the test method. The test leader has to note the geometry of the staircase in use. The average height of the risers and treads is measured. Whether the risers have kick plates or not is noted. The left and right sides of the stairs are marked as being either open or closed. Whether risers or sides of the steps are open or closed is important because some robot algorithms or tele-operative techniques may rely on there being solid material in the riser portion or adjacent to the steps. The number of steps between landings is counted.

The test method entails having the operator navigate the robot up the stairs and back down. The total number of steps completed is counted and the amount of time required is noted. As with the other test methods, a time limit was imposed due to logistical considerations, but the intended test method would allow as much time as necessary to complete a round trip on the stairs. An average rate (time/step) is calculated for the test.

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STAIRS

ROBOT: ________________ ☐ TETHER ☐ RF

OPERATOR: ________________ ORG: ________________

SKILL LEVEL: ☐ NOVICE ☐ INTERMEDIATE ☐ EXPERT

INSTRUCTIONS: 1) NOTE THE AVERAGE STEP RISER AND TREAD DIMENSIONS. 2) NOTE THE WALL CONDITIONS AS SOLID OR OPEN. 3) TIME SEQUENCE FOR ROBOT TO ASCEND AND DESCEND THE STAIRS. 4) NOTE THE NUMBER OF STAIRS AND LANDINGS (GREY) ASCENDED. 5) NOTE THE ELAPSED TIME. 6) RESTART TIMING FOR DESCENT.

STEPS : ____

STEPS : ____

STEPS : ____

STEPS : ____

STEPS : ____

STEPS : ____

STEPS : ____

STEPS : ____

STEPS : ____

	ASCENDING	DESCENDING
START TIME:	________	________
END TIME:	________	________
ELAPSED TIME:	________ s	________ s
TOTAL STEPS:	________	________
	(COUNT LANDINGS AS A STAIR)	
AVG RATE:	________	________
	(COUNT LANDINGS AS A STAIR)	

LEFT WALL (ASCENDING): ☐ SOLID ☐ RAILING ONLY

RIGHT WALL (ASCENDING): ☐ SOLID ☐ RAILING ONLY

RISER DIMENSION: ________ cm ☐ WITH KICK-PLATE ☐ WITHOUT KICK PLATE

TREAD DIMENSION: ________ cm

TEST LEADER

DATE

NOTES ☐

Figure 12: Mobility - Stair Climbing Test Method Data Capture Form

Mobility – Ramps

This test method addresses responder requirements for mobility on sloped surfaces, including roofs. Rather than submitting a single formal artifact into the standards process, it is envisioned that a range of angles and surface types will be included in the test method definition.

As can be seen in the data collection form in Figure 13, the angle of the ramp must be measured. Ideally, the material and/or coefficient of friction will also be another quality that is captured on the test method form. The robot is to traverse a sequence of waypoints as shown on the schematic in the form. The waypoints are marked upon the ramp to guide the operator. The operator must start at location 1 and move the robot to location 2, then 3, and so on, in sequence. This forces there to be different combinations of robot orientation and direction of travel with respect to slope of the ramp. The distances between each leg of the pattern is measured and the time it takes for the robot to complete the whole circuit is measured. In practical implementations, the angle of the ramp would be raised each time the robot successfully completes a circuit. The data collection is continued until the ramp reaches an angle that is too steep for the robot to complete the entire circuit.

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RAMPS

ROBOT: ________________ ☐ TETHER ☐ RF

OPERATOR: ________________ ORG: ________________

SKILL LEVEL: ☐ NOVICE ☐ INTERMEDIATE ☐ EXPERT

INSTRUCTIONS: 1) CIRCLE THE INCLINE ANGLE. 2) TIME THE SEQUENCE FOR THE ROBOT TO TRAVERSE THE PATTERN SHOWN, TOUCHING EACH TARGET. 3) NOTE THE ELAPSED TIME AND NUMBER OF LENGTHS IF NOT COMPLETE.

INCLINE (CIRCLE ONE):

90° VERTICAL WALL

......

30°

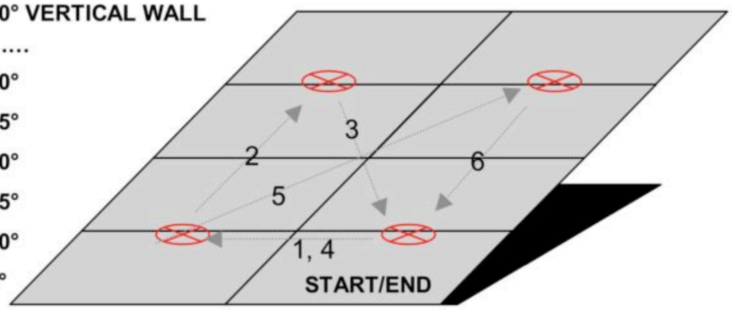
25°

20°

15°

10°

5°



START TIME: ________

END TIME: ________

ELAPSED ________ s

LENGTHS: ________

INCLINE (CIRCLE ONE):

90° VERTICAL WALL

......

30°

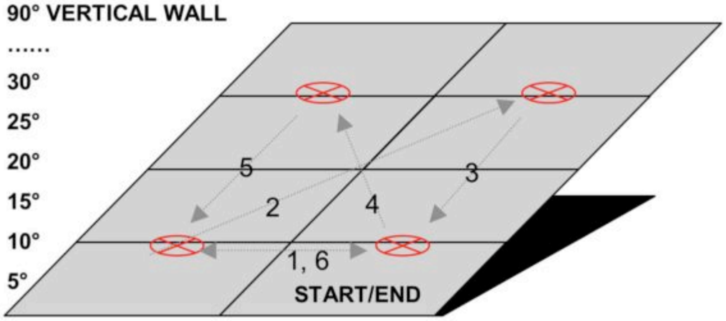
25°

20°

15°

10°

5°



START TIME: ________

END TIME: ________

ELAPSED ________ s

LENGTHS: ________

TEST LEADER DATE NOTES ☐

Figure 13: Mobility - Ramps Test Method Data Capture Form

Mobility – Confined Space Access

The confined space access test methods addresses responder requirements for access to tight spaces. This test uses a variant of the NIST step fields that has an inverted set of step fields projecting from above to narrow the traversable volume.

Figure 14 shows the test method data capture sheet for the test. The artifact employed is a confined space cube. As with most other test methods, the artifacts for this are constructed from pallet-sized units. The customization allowed for necessitates that the test leader capture the following information on the test form for each pallet unit:

- The dominant (highest) geometry of the random step fields for both the roof and floor: diagonal or hill. This is marked directly on the schematic representation
- The post heights for each cube (in terms of multiples of a unit cube).
- Total number of pallets

For the test data capture, the robot is to traverse the length of the set of confined cubes. The number of pallets it can traverse is noted along with the time for it to do so.

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CONFINED SPACE CUBES

ROBOT: ________________ ☐ TETHER ☐ RF

OPERATOR: ________________ ORG: ________________

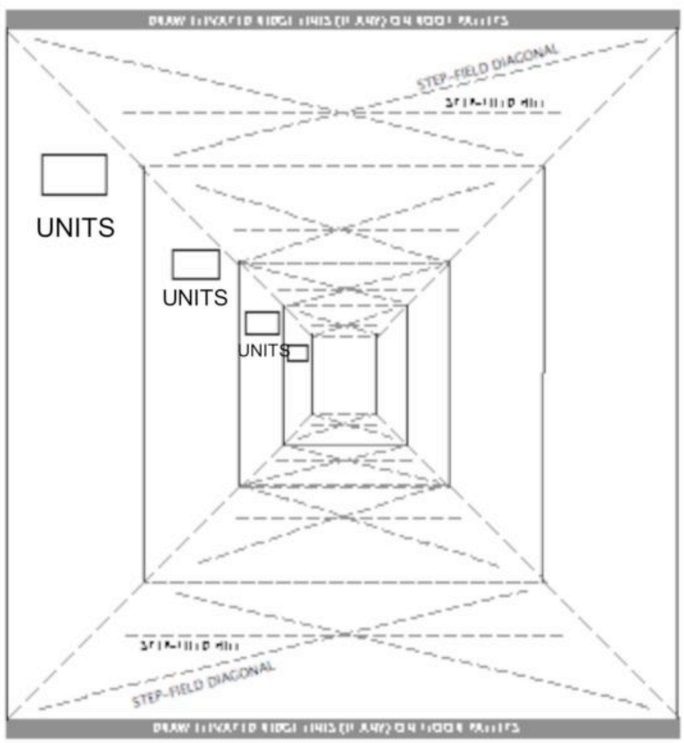
SKILL LEVEL: ☐ NOVICE ☐INTERMEDIATE ☐EXPERT

INSTRUCTIONS: 1) TRACE ELEVATED TERRAIN RIDGES BOTH ON FLOOR PALLETS AND ROOF PALLETS. 2) NOTE THE POST HEIGHTS FOR EACH PALLET IN STEPFIELD CUBIC UNITS. 3) TIME SEQUENCE FOR ROBOT TO TRAVERSE THE CONFINED SPACE PROGRESSION TO FAR END. 4) NOTE THE ELAPSED TIME AND TOTAL PALLETS TRAVERSED COMPLETELY (NO LONGER TOUCHING).

START TIME: __________ TOTAL PALLETS: __________

END TIME: __________

ELAPSED: __________



TEST LEADER DATE NOTES ☐

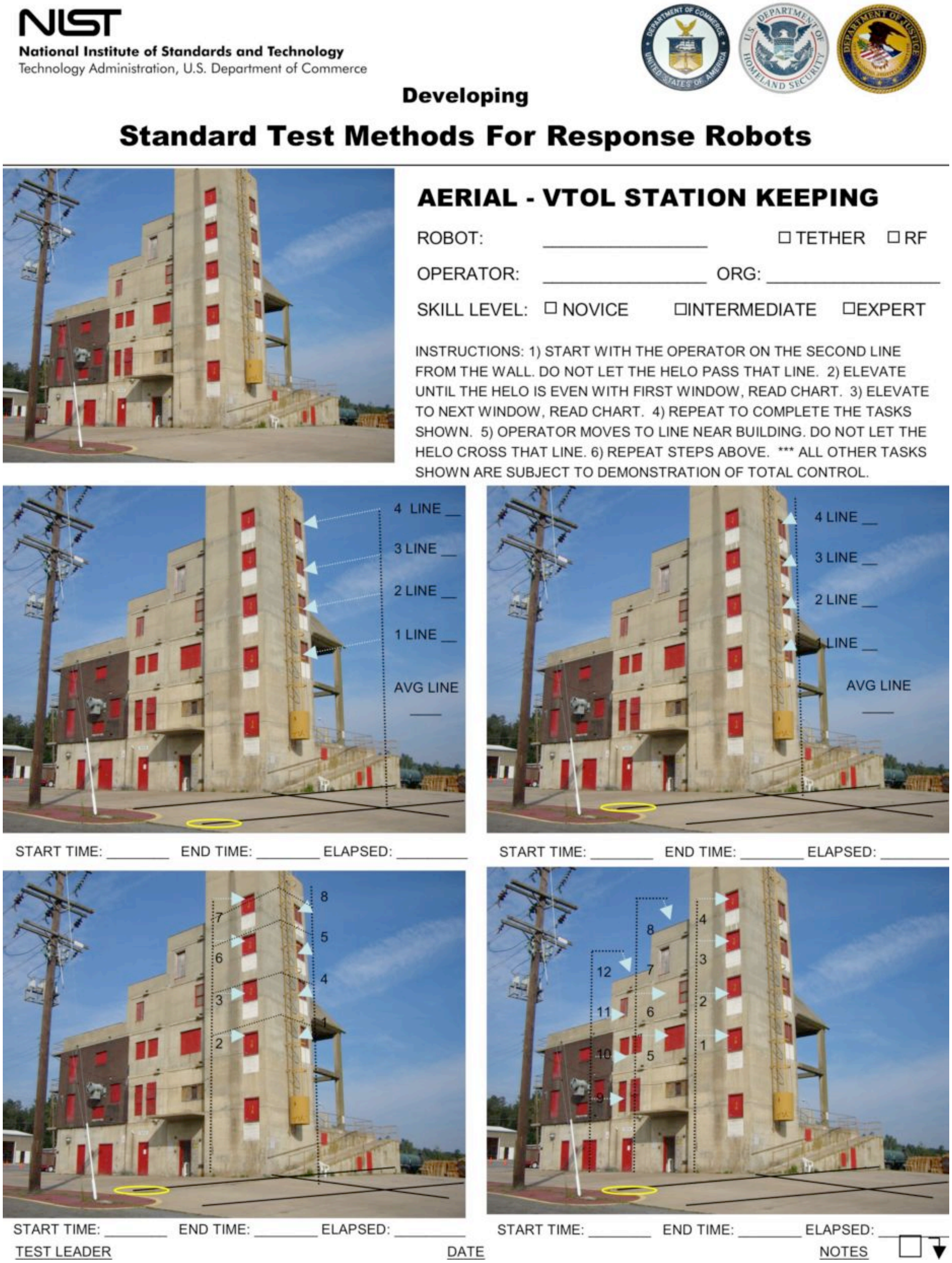
Figure 14: Mobility - Confined Space Access Test Method Data Capture Form

Aerial – Vertical Takeoff and Landing (VTOL) Station Keeping

This test method addresses a newer requirement that surfaced during the April 2006 exercise held at Disaster City[3]. Responders articulated a need to control the path of an aerial vehicle and in particular to be able to hold a given position so as to be able to perform a task, such as reading hazardous materials stickers or looking for victims through windows.

Figure 15 shows the form used in the Montgomery County exercise to conduct this test method. A vertical takeoff and landing (VTOL) aerial vehicle was to move to predetermined positions (windows) in the building, as noted in the forms. The numbers in the picture indicate the sequence in which the vehicle was to align itself with the locations. At each station, there was a target, a visual acuity eye chart, which the operator was to read. The smallest line that the operator could read was noted at each position. There were two pre-set distances that were to be maintained offset from the building (shown as the first and second lines). The test leader was to ensure that the vehicle did not cross the currently designated offset line. The total time required to conduct each set of movements, positioning, and reading of eye charts was measured.

[3] http://www.isd.mel.nist.gov/US&R_Robot_Standards/disaster_city/Workshop5_April2006.pdf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AERIAL - VTOL STATION KEEPING

ROBOT: ________________ ☐ TETHER ☐ RF

OPERATOR: ________________ ORG: ________________

SKILL LEVEL: ☐ NOVICE ☐INTERMEDIATE ☐EXPERT

INSTRUCTIONS: 1) START WITH THE OPERATOR ON THE SECOND LINE FROM THE WALL. DO NOT LET THE HELO PASS THAT LINE. 2) ELEVATE UNTIL THE HELO IS EVEN WITH FIRST WINDOW, READ CHART. 3) ELEVATE TO NEXT WINDOW, READ CHART. 4) REPEAT TO COMPLETE THE TASKS SHOWN. 5) OPERATOR MOVES TO LINE NEAR BUILDING. DO NOT LET THE HELO CROSS THAT LINE. 6) REPEAT STEPS ABOVE. *** ALL OTHER TASKS SHOWN ARE SUBJECT TO DEMONSTRATION OF TOTAL CONTROL.

START TIME: ________ END TIME: ________ ELAPSED: ________

START TIME: ________ END TIME: ________ ELAPSED: ________

START TIME: ________ END TIME: ________ ELAPSED: ________

START TIME: ________ END TIME: ________ ELAPSED: ________

TEST LEADER DATE NOTES

Figure 15: Aerial - VTOL Stationkeeping Test Method Data Capture Form

5. Summary of Radio Communications Test Method Trials

Performance testing in representative radio environment

During the exercise, representatives from the NIST Electromagnetics Division administered the draft Line of Sight (LOS) and Beyond Line of Sight (BLOS) Radio communications tests. BLOS is also sometimes referred to as Non-line of Sight (NLOS). They also gathered a substantial amount of data on the technical specifications of various US&R robots and on the typical radio environment. Figure 16 shows the setup of the tests.

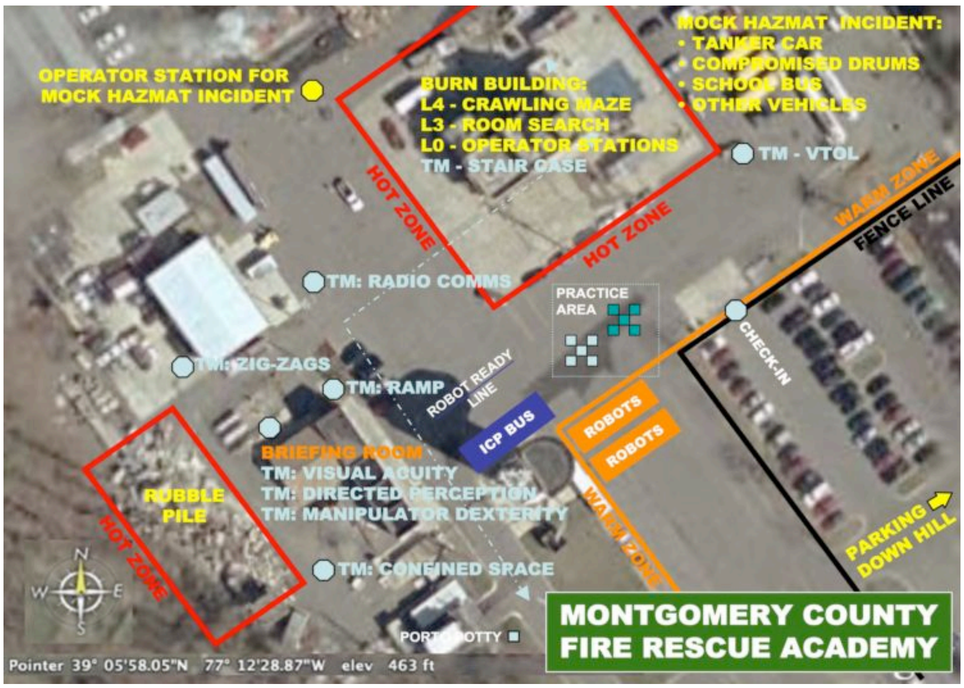


Figure 16: Overview of the US&R robot test site in Montgomery County. The light blue dashed line shows the radio communication test paths. The top line shows the non line of sight tests going to the right and then to the back of the burn building. The lower line shows the line of sight test going along the driveway.

In both the line-of-sight and non-line-of-sight tests the operator and test administrator were stationed in a fixed location (see the dot labeled "TM: RADIO COMMS" in Figure 16). In the LOS test, the robot moved away from the operator down a long driveway. Markers were placed at 100m, 150m, 200m, and 250m. Video reception from and control of the robot were checked at each marker. For the NLOS tests, the robot moved about 65m away in an LOS condition, then turned the corner behind a building, which provided the NLOS condition. Markers were placed every 3m behind the building to test if and when the robot lost data and control capabilities.

Data that were collected include:

- frequency of operation
- type of data transmitted (i.e., video or control)
- output power level
- hardware such as antennas and antenna placement
- radio-interference environment
- physical environment

We saw that each of the above interacted, providing more- or less-successful transmissions for the various robots deployed in the tests. In particular, the radio interference environment had a profound effect on the robots' ability to successfully complete the tests. Several of the robots used similar frequency bands and wireless access schemes such as 802.11b. Those with higher power levels often drowned out those with lower power levels, and in some cases robots with similar power levels still interfered with each other. Interference was the most significant impediment to radio communication success and had a serious-to-catastrophic negative impact on 10 out of the 14 robots we tested.

Summary of the Data

Physical Environment: The environment was relatively open with only a few large structures in the area. One was a several-stories-tall radio tower with a small footprint located tens of meters from the test area. This building was made of concrete, as was the "burn building", a five-story tall concrete building where our NLOS tests were carried out. The ground was covered with a concrete or asphalt surface throughout the test area. A map of the area, with dashed lines indicating where the radio communications tests were carried out, appears in Figure 16.

Radio Interference Environment: As mentioned above and as can be seen in the data below, most of the robots operate in the "industrial, scientific, and medical," or ISM frequency bands. There is no regulation for licensing or frequency coordination in these frequency bands, thus the spectrum is readily available for use in commercial applications. While protocols that minimize interference between systems in these bands were often used by the robot designers, when the ISM frequency bands get crowded or when one user has a much higher output power than the others, interference can occur – even on frequencies quite removed from the robot under test. We saw cases where transmitters in the 1760 MHz band knocked out video links in the 2.4 GHz frequency band.

Observations Based on Data Collected

Our tests indicate that a high percentage of the robots had problems with radio interference. In many cases, this interference led to failure of the test. The issue of radio interference clearly needs to be addressed not only because it degrades the reliability of US&R robot performance in certain situations, but also because it may impact our ability to develop meaningful standards for radio communications. This is because the performance metrics and functional tests that are developed will at least partially depend on frequency of operation, radio interference environment, and modulation schemes generally used by robot designers.

Responder Survey on Communications Requirements

We also distributed a survey to the responders asking them the distances they would need for radio communications for US&R robots in a number of scenarios. The answers will be useful in developing performance metrics for US&R robot in the ASTM standard. The survey answers appear in Table 2.[4]

[4] Note that distances are reported in English units instead of SI. This is due to the responders' greater familiarity with English units.

Table 2: Responder answers to the question "Please give us a rough idea of the communication requirements for the emergency environments where your organization users/would use USAR robots"

HazMat Situation			Building Collapse			Standing building survey		
Ideal range (open air/ inside structure)	Marginal range (open air/ inside structure)	Minimum range (open air/ inside structure)	Ideal range (feet in rubble)	Marginal range (feet in rubble)	Minimum range (feet in rubble)	Ideal range (number of interior walls)	Marginal range (number of interior walls)	Minimum range (number of interior walls)
3000'/ 2000'	2000'/ 1000'	500'/350'	300'	150'	30'	30	20	10
1000'/ 300'	500'/250'	150'/250'	2000'	1000'	500'	10	5	3
1500'/ 500'	750'/250'	500'/50'	1500'	750'	500'	15	10	5
1500' (would prefer 5 miles)	1000'	500'	500'	350'	200'	6	5	4
500'+	400'	300'	150'+	100'	100'	6	5	3
300'/ 3 levels in NY sub-way	same	same	same	same	same	3 levels in subway	same	same
2000'	1200'	1000'	1000'	750'	500'	10	8	5
400m	--	200m	200m	--	100m	10	--	4

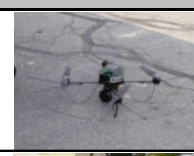
6. Informal Testing of Radiation Sensors with Robots

Key desired mission payloads for robots in Urban Search and Rescue (and other) applications include sensors for detecting and monitoring radiation. This exercise provided an excellent opportunity to bring together the radiation sensing and robotics communities and to conduct initial experimentation with *ad hoc* integration of the sensors on-board the robots as well as informal evaluations of already integrated sensors. Engineers and physicists from NIST who are developing standard tests for radiation sensors and who have expertise in conducting testing and evaluation of these sensors invited sensor manufacturers to participate in the event. The NIST Radiation Physics staff designed and conducted several experiments at the Montgomery County Facilities, designed to explore the issues in testing and measuring radiation sensing using robots.

Radiation sources were inserted into an outdoor setup of the Directed Perception Test Method artifacts (see above) for structured testing of the ability to detect the sources using sensors mounted on robots. Radiation sources were also placed within one of the scenarios. This provided an opportunity to experience a more free-form and realistic mission using the radiation sensors with robots.

Four radiation detectors were brought by their manufacturers. These were integrated with robots and the integrated system was informally evaluated. Four robots already had integrated sensors (Table 3). The drawback was that the connection and software are unique to the sensor-robot pairing.

Table 3: Robots with Integrated Sensors

Robot	Capability	Image
AirRobot	Radionuclide identification (RID) system weighing less than 200 g	
BOZ-01	Radiation/Biological/ Chemical Sensors	
Matilda	Radiation/Biological/ Chemical Sensors (infra-red port)	
Negotiator	Radiation/Biological/ Chemical Sensors (serial port)	

For sensors that were mounted onto robots in an *ad hoc* fashion during the exercise, there were several issues to contend with. The possibility of having the sensor mounted onto a robot was guided by the weight and size of the sensor. Ideally, the robot would have a manipulator that could hold the sensor in a secure fashion, in order to access interior voids and have a greater overall range of spatial coverage. Since the sensors were not integrated with the robots, a method had to be devised for viewing the display on the sensor face and/or receiving the audible signal at the remote location where the operator was located. In some instances, it was possible to aim robot cameras at the sensor display or use an microphone on the robot to receive information remotely.

On the first day of the exercise, the Radiation Physics staff worked with radiation sensor and robot company representatives to identify which robots could incorporate sensors and which pairings were the best matches, based on the criteria discussed in the previous paragraph. Radiation sources were placed in locations within the “practice area” as shown in Figure 17. Measurements were taken to validate that the sources could be located and to verify the sensor responses. Baseline tests were initially conducted with the standalone sensors.

The results from the first day were the following:

- Sensors were able to detect and identify ^{137}Cs (32 μCi) and ^{133}Ba (148 μCi).
- Sensors mounted low on robots were not able to detected the ^{137}Cs.
- All sensors were able to detect the ^{133}Ba.
- Readings were taken by sensor manufacturers as wireless communication and robot cameras had trouble reading sensor displays.

Figure 17: "Practice Area" which was used for initial training and experimentation by participants.

On the second day of the exercise, robots were again matched with radiation sensors (Table 4, Figure 19). Sources were placed in different scenarios (Fig 18): ^{232}Th in the train, ^{137}Cs + ^{232}Th within a set of drums, and ^{133}Ba in a tanker. Measurements were performed to locate sources and verify sensor response. Responders operated the robots and tried to locate the sources.

Table 4: Sensor-Robot Matching

Sensor	Robot
Mini Radiac Inspector 1000	Matilda
InSpector 1000	Bombot
InSpector 1000	Matilda EOD
ICS 4000	DragonRunner
InSpector 1000 and ICS 4000	Packbot
ICS 4000	Bombot
ICS 4000	Boz-01

Figure 18: Scenarios into which sources were placed.

DragonRunner + ICS 4000

Matilda EOD + InSpector 1000

BomBot + ICS 4000

PackBot EOD

Figure 19: Images of Robots With Sensors Attached

Observations from the integrations are listed below. Issues are noted to inform the robot and sensor manufacturers in their future designs. The robots and sensors were not designed to take into account this integration, so it is not surprising that problems resulted. It was a good initial opportunity to begin the requirements definition for having onboard radiation sensors to be used by responders. This information will be used to help guide the design of the test methods for onboard radiation sensors in future waves of standards.

- Not all robots had audible capabilities (microphone, speaker), so the responders operating the robot remotely could not utilize sound alerts coming from the sensors.
- Some sensors were able to relay information back remotely through a wireless communication. There were interference problems with robot wireless communications. This echoes the interference problems noted amongst the different robots.
- Cameras often could not read sensor displays. The resolution and lighting were not sufficient to see the displays.
- There were sensor mounting issues. Trying to deploy the sensor high above the robot requires mounting to an arm.
- There were weight limitations encountered due to robot payload limits.

Lessons Learned and Needs

- For sensor plug-and-play capability on robots need to:
  - Define wire connection in robot
  - Define communication protocol between sensor and robot (2-way communications)
  - Transmit ANSI N42.42 data format (XML) files to save spectra and data
  - Define display integrated into robot control unit

- Cameras are not very useful as sensor screens were not readable with sun light

- Need audible capability – Radiation sensors need to meet 85 dB at 30cm

- Sensor mounting capabilities will depend on type of mission

- High sensitivity instruments gross counting and/or ID capabilities

7. Data Collection

This event provided a focused opportunity to capture feedback from responders and manufacturers. Questionnaires regarding the scenarios and the test methods captured the impressions of all the stakeholders. Further feedback was collected from the responders only during a "Hot Wash" review meeting immediately following the event. Copious images and video of the robots in action were also collected. This section describes briefly the data collected.

7.1 Images and Video

The organizers collected images and videos of robots and personnel participating in the event. Each robot developer receives all media related to their robots. Highlight images and generally successful robot videos can be found on the NIST project home page: http://www.isd.mel.nist.gov/US&R_Robot_Standards/.

7.2 Test Results

Robots were assigned to run through all tests that were relevant or feasible for their particular design. Most robots were able to attempt all of the tests for which they were eligible. Test proctors collected data per the draft test methodology on the appropriate data sheets, which were shown in Section 4.

The process of capturing data was evaluated by the test proctors and others. Critiques of the test methodology and artifacts from responders and robot developers were solicited. The actual data collected was analyzed post facto, primarily to establish ranges of performance for finalizing the test methods prior to submitting them to the standards balloting process.

NIST is not releasing the results of the test methods from this exercise. The test methods are still under development, hence it is not expected that robots be officially measured. Robot developers have voluntarily participated in this event, knowing that this was a learning opportunity for all and it would not be fair to publish test results at this time.

Appendix A -- Participants

LAST NAME	FIRST NAME	COMPANY
Ahed	Jameel	Robotic FX, Inc
Alderson	Doug	NIST
Allgrove	Chip	RAE Systems
Alvarez	Jaime	BOZ Robotics
Antonishek	Brian	NIST
Aoki	Takeshi	Tokyo Tech
Arai	Masayuki	Tokyo Tech
Balaguer	Ben	NIST
Balakirsky	Steve	NIST
Bean	Bob	WVHTC
Best	Buck	VA-TF1
Blitch	John	ARACAR
Boogard	Parry	WA-TF1
Bustilloz	George	iRobot
Butler	Carey	WVHTC
Carmichael	Kevin	Canberra
Cheok	Gerry	NIST
Cochran	Ronald	WVHTC
Cole	Mike	Mesa Robotics
Conditt	Mike	Lincoln Fire and Rescue
Cope	John	Envision Product Design LLC
Coursey	Bert	DHS
Crowley	William	Automatika, Inc.
Detrick	Tony	TSWG/Battelle
Downs	Tony	NIST
Eames	Dexter	XRF Corporation
Ellis	Angie	NIST
Evans	John	John Evans LLC
Flint	Bob	Robotic FX, Inc
Ford	Carolyn	DoC
Gross	Ashley	iRobot
Haus	Lee	CA-TF1
Haus	Tom	CA-TF1
Hough	George	NY-TF1
Hundley	Mark	VA-TF2
Ingledue	Jim	VA-TF2
Karam	Lisa	NIST
Keyes	Brenden	U of Mass, Lowell
Kooistra	Danny	Global Technical Systems
Koyanagi	Eiji	Chiba Institute
Lang	Erin	RAE Systems
Lesh	Dave	CA-TF6
Lockwood	Tom	National Capital Regions Homeland Security Office
Lynch	Laura	XRF Corporation
Lytle	Alan	NIST
Madhavan	Raj	NIST
Magin	Jon	BOZ Robotics
Matsuno	Fumitoshi	Shinobi

Mayers	John	VA-TF1
Mengers	Tim	NIST
Meyer	Thomas	AirRobot
Micire	Mark	U of Mass, Lowell
Miyanaka	Hitoshi	Shinobi
Movalson	Bill	Envision Product Design LLC
Movalson	Mary Kay	Envision Product Design LLC
Naslund	Bruce	MA-TF1
Nielsen	Curtis	Idaho National Labs
Nogushi	Hiromi	Chiba Institute
Nohe	Dean	Global Technical Systems
Norman	Bruce	NIST
Ohta	Yusuke	Tokyo Tech
Parish	Dave	Omnitech Robotics
Parker	Billy	TX-TF1
Parker	Cathy	iRobot
Pibida	Leticia	NIST
Poulter	Andrew	ARA
Pursley	John	Envision Product Design LLC
Pursley	Sandi	Envision Product Design LLC
Quinn	John	CO-TF1
Remley	Kate	NIST
Russell	Debbie	NIST
Ryden	Tom	iRobot
Salvermoser	Jeanenne	NIST
Sato	Noritaka	Shinobi
Savant	Sameer	Mesa Robotics
Schempf	Hagen	Automatika, Inc.
Schipani	Sal	NIST
Schlenoff	Craig	NIST
Schmoll	Frank	AirRobot
Scrapper	Chris	NIST
Sheh	Raymond	University of New South Wales
Shigeo	Hirose	Tokyo Tech (Hibot)
Stair	Gary	iRobot
Steed	Mike	MD-TF1
Stover	Sam	IN-TF
Tadakuma	Kenjiro	Tokyo Tech
Tadokoro	Satoshi	IRS
Thieben	William	XRF Corporation
Unterweger	Mike	NIST
Virts	Ann	NIST
Walton	Avery	Health Physics
Weber	Eric	Robotic FX, Inc
Wiggerich	Burkhard	AirRobot
Winesett	Nate	Global Technical Systems
Yanco	Holly	U of Mass, Lowell
Yoshisa	Tomoaki	Chiba Institute